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Immobilization of leachate's heavy metals using soil-zeolite column

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Abstract

Introduction: Soil hazardous heavy metal pollution is increasingly a decisive problem all over the world. One of the problems associated with organic fertilizer factories is the discharge of leachate containing solid wastes. The leachate percolates through the soil and where there is no proper leachate filtration, this discharge could be potentially a primary pollution source of soil and water resources. Iran has limited water resources and oppositely large number of unused lands. Therefore, properly managed land treatment may be a suitable solution for the filtration of leachate before it enters the environment or is reused as irrigation water. To investigate the potentiality of soil-zeolite in the immobilization of heavy metals and prevention of groundwater contamination, a lysimeter study was performed with two types of soil texture (clay loamy and loamy sand) and two levels of zeolite and a blank (0, 5, and 10%).

Results: The results showed that soil with a clay loamy texture can adsorb heavy metals such as Cr^{3+}, Pb^{2+}, Ni^{2+}, and Cd^{2+} from influent leachate stronger than soil with loamy sand texture. Application of zeolite had a significant effect ($p < 0.05$) on Pb^{2+}, Ni^{2+}, and Cr^{3+} concentration in the effluent. Increasing applied zeolite, reduced the concentrations of these heavy metals in the effluent. Furthermore, application of zeolite and irrigation with leachate decreased the bulk density, hydraulic conductivity, and infiltration of the soil in all treatments.

Conclusion: Briefly, this research indicated that land treatment is a good way to reduce leachate electrical conductivity (EC) and elimination of leachate heavy metals.

Keywords: Heavy metal; Infiltration; Leachate; Saturated hydraulic conductivity; Zeolite

Introduction

The moisture content of urban solid wastes in Iran is very high. Therefore, a large volume of leachate is produced during the process of converting wastes into compost. The leachate contains large amounts of organic matter, plant nutrients, and soluble salts as well as some heavy metals Kalbassi and Gandomkar (1997). Hence, it is necessary to refine the leachate of urban solid wastes before it has the chance to enter the environment or is reused.

Conventional wastewater treatment technologies are cost-intensive and often pose financial constraints for developing countries. Therefore, considerable attentions have been directed toward the design and development of low-cost wastewater management technologies with recycling and reuse benefits (Ackley and Yang 1991; Thawale et al. 2006).

Land treatment is accomplished by biological, chemical and physical interactions in the soil matrix at the surface layers, which comprises the most active zones of the soil. Land treatment is a practice of spreading contaminated soils or wastes on the surface of the ground to facilitate natural microbial degradation of contaminants. This process is defined as the application of municipal and industrial wastewater in the land at a controlled rate. The purpose of this treatment system is to obtain beneficial use of these materials, to improve environmental quality, and to achieve treatment goals in a cost-effective and environmentally sound manner. The direct discharge of effluent in soils can be used as a primary or secondary treatment and offers opportunities for groundwater recharge and wastewater storage. The effects of wastewater on soil, subsurface water,

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and plants completely depend on the type and content of the wastewater, the soil texture, and the prevailing conditions in the soil Bhardwaj et al. (2007).

In recent years, natural substances such as zeolite have been used to adsorb heavy metals from water Ouki and Kavannagh (1999) and from soil to decrease their availability to plants (Mondale et al. 1995; Inglezakis et al. 2002). Zeolite is a natural material that has been studied extensively for its remediation potentiality of hazardous heavy metal-polluted soils Shanableh and Kharabsheh (1996). Compared to other techniques, zeolite application is fast, clean, and inexpensive Mahabadi et al. (2007). Zeolite consists of crystallized silicate with a porous structure. This material has been the subject of great interest in a wide array of applications Breck (1974). Zeolites, as natural cation exchangers, are suitable to remove toxic cations Mondale et al. (1995; Inglezakis et al. 2002). Among the natural zeolites, clinoptilolite seems to be the most efficient ion exchanger and ion-selective material Bittell and Miller (1974) for removing and stabilizing heavy metals Echeverria et al. (1998). It has a high specific surface area and superior capability for adsorption, cation exchange, and catalyzation Leppert (1990). Application of zeolite in the soil can retard the migration of leachate and, as a result, allow the exchange and/or decomposition of heavy metals Shi et al. (2009). Leachate land treatment can affect the physical or chemical properties of the soil, such as hydraulic conductivity, infiltration, electrical conductivity (EC), the presence of heavy metals, and the cation and anion content.

Iskander et al. (2011) showed the possibility of using natural zeolite and bentonite as slow release fertilizers for Zn and Mn and also as soil pollution preventers. Zn in the case of zeolite showed the lowest desorbed percentage particularly at high levels of sorbed Zn. After three successive extractions, only 74.7% was readily extractable by diethylenetriaminepentaacetic acid (DTPA) excluding 25.3% Zn retained by the mineral whereas in the bentonite case, 82.26% of sorbed Zn was readily extractable by DTPA excluding 17.74% Zn retained by the mineral. In the case of Mn, 84.63% of Mn sorbed by zeolite was readily extractable by DTPA apart from 15.37% Mn retained by the mineral. In the case of bentonite, 89.79% of adsorbed Mn was readily extractable by DTPA, exclusive of 10.21% Mn retained by the mineral. In all treatments three successive extractions were implemented. Tabatabaei et al. (2012) demonstrated that adding zeolite to clay loam had no significant effect on the chemical oxygen demand. Sandy loam with zeolite had high significant impact on the removal capacity of total coliform (TC); oppositely, clay loam had no impact on the removal capacity of TC. Clay loam implemented better performance than the sandy loam soil on Na, Ca, and Mg adsorption.

Table 1 Chemical and physical characteristics of the zeolite sample

Parameter	Value/description
P_2O_5 (%)	0.01
MnO (%)	0.04
Fe_2O_3 (%)	1.30
TiO_2 (%)	0.21
K_2O (%)	3.12
Na_2O (%)	2.01
MgO (%)	0.80
CaO (%)	3.10
Al_2O_3 (%)	11.80
SiO_2 (%)	66.50
LOI[a]	12.05
Color	Light green
Mineral (%)	85 to 95
CEC (mEq $100 \cdot g^{-1}$)	100
ρ_s[b] ($g \cdot cm^{-3}$)	2.40
ρ_b[c] ($g \cdot cm^{-3}$)	1

[a]Loss of ignition, [b]Particle density, [c]Bulk density.

The focus of this paper is to investigate the potential of soil-zeolite in the immobilization of heavy metals and the effect of leachate on physical properties of soil in the presence of zeolite.

Methods

Zeolite sampling

The natural zeolite (Clinoptilolite zeolite) used in this study originated from Semnan province, Iran. The cation exchange capacity (CEC) value of this sample was 100 meq $100 \cdot g^{-1}$. Table 1 shows the chemical and physical characteristics of the zeolite sample used in this experiment.

Site description

The study was conducted at Organic Fertilizer factory located in the east of Isfahan at the central part of Iran. In the study area, the mean annual temperature, rainfall, and humidity are 17°C, 134 mm, and 38%, respectively. A complete randomized block design experiment with six treatments was applied (A0: loamy sand soil, A5:

Table 2 Physical characteristics of the soil applied to the lysimeters

Characteristic	Loamy sand	Clay loam
Hydraulic conductivity ($m \cdot day^{-1}$)	3.02	1.58
Electrical conductivity ($dS \cdot m^{-1}$)	0.34	0.38
pH	6.85	6.54
Organic carbon (%)	0.10	0.48

Table 3 Physicochemical analyses of influent leachate

SAR	pH	EC	Cl^-	HCO_3^-	Na^+	Ca^{2+}	Mg^{2+}	TDS	TSS	Cr^{3+}	Cd^{2+}	Pb^{2+}	Ni^{2+}
		$dS \cdot m^{-1}$	$Mg \cdot L^{-1}$										
11.88	4.70	39.32	10,472	32,395	5,175	8,320	3,660	58,400	9,026	1.07	0.12	1.25	2.62

loamy sand soil mixed with 5% zeolite, A10: loamy sand soil mixed with 10% zeolite, B: clay loamy soil, B5: clay loamy soil mixed with 5% zeolite, and B10: clay loamy soil mixed with 10% zeolite) and three replications were performed in 18 PVC soil columns filled with treatment soils (60-cm diameter and 100-cm height with a drain pipe at the bottom). The physical characteristics of the two types of soil used in this study are listed in Table 2. A 10-cm layer of fine sand was placed in the bottom of each lysimeter as a filter, and the next 60 cm was filled with the treatment.

Leachate from Isfahan Organic Fertilizer factory was used as the influent in the lysimeters. The physicochemical properties of the leachate are given in Table 3. Influent application was scheduled bi-weekly, and the total number of influent application through the study period was 16. The amount of applied influent for all treatments was 5 cm in each influent application event. The total amount of applied leachate for each lysimeter was approximately 226 L. Figure 1 shows a schematic drawing of the lysimeter.

Data collection

The leached solution was collected weekly from each lysimeter by opening the drainage valve located at the end of drainage pipe. The drainage samples were subjected to analysis for electrical conductivity (EC) and pH value. EC was determined using a conductivity meter, and pH was measured with a pH meter. The concentrations of cadmium (Cd^{2+}), nickel (Ni^{2+}), chromium (Cr^{3+}), and lead (Pb^{2+}) in effluent samples were specified by standard methods during the study period APHA (1995). Heavy metal concentrations were measured using an atomic adsorption spectrometer (PerkinElmer 3030, Waltham, MA, USA). At the end of the study, undisturbed soil samples were collected from each lysimeter using a core sampler. The bulk density and particle density of the soil samples were calculated using the cylinder and picnometer methods, respectively Klute (1986). The hydraulic conductivity of the soil was identified in each lysimeter using constant (for clay loamy soil) and falling head (for loamy sand soil) methods Shanableh and Kharabsheh (1996).

Data analysis

The percentage of removed heavy metal was calculated by the following formula:

$$E = 100 * (C_i - C_e)/C_i, \quad (1)$$

where C_i is the metal concentration in the influent leachate sample in $mg \cdot L^{-1}$ and C_e is the metal concentration in the effluent leachate sample in $mg \cdot L^{-1}$.

All analyses were performed using SAS statistical analysis SAS (1987). Separation of means was performed using LSD at $p < 0.05$.

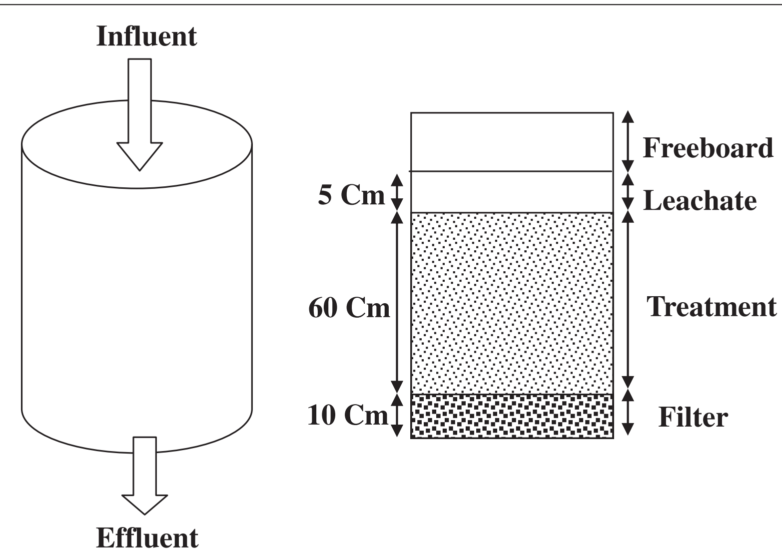

Figure 1 A schematic drawing of the lysimeter.

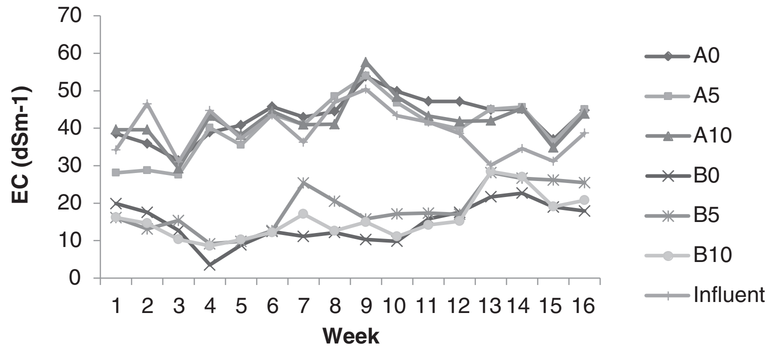

Figure 2 Changes in the influent and effluent EC in all treatments.

Results and discussion

EC

EC is typically used to indicate salt concentration in solution. Figure 2 shows the value of the EC for the influent (leachate from the fertilizer factory) and the effluent of each treatment during the study. The EC of the influent was measured within the range of 30 to 50 $dS \cdot m^{-1}$ during the experiment, which indicates the complex ion composition of this kind of wastewater. Application of zeolite had no effect on the effluent EC in the loamy sand lysimeter. In the first 4 weeks, the effluent EC calculated in these lysimeters was lower than the influent EC (Figure 1). During the mentioned weeks, the maximum difference between the influent and effluent EC values was 17 $dS \cdot m^{-1}$. After this period, the effluent EC values measured in these lysimeters increased, and after week 9, it was higher than the influent EC value. This result could possibly be due to accumulation of salts in the soil during the first weeks and leaching these elements at the end of study. Hatt et al. (2007) demonstrated the fact that concentrations of heavy metals and phosphorus in outflow may increase along with time, because of the slow washing of fine particles through the filter and/or desorption of the elements due to changing pH and oxygen levels as the filter clogs. During the study period, the EC of the effluent from the clay loam lysimeters was lower than the EC of the influent, which was between 3.5 to 27 $dS \cdot m^{-1}$.

The results also showed that soil type had a significant effect ($p < 0.05$) on the effluent EC value and the lowest effluent EC value was found in lysimeters with clay loamy soil texture. The mean value of the effluent EC for clay loamy and loamy sand soil texture were 16.28 and 41.87 $dS \cdot m^{-1}$, respectively. Because clay loamy soil has a higher cation exchange capacity, it was able to adsorb positive cations such as sodium and, as result, decrease the value of the effluent EC up to more than 60%. The level of zeolite added to the soil had a significant effect ($p < 0.05$) on the effluent EC value. In more detail, by adding 5% and 10% natural zeolite to the soil, the mean effluent EC values were 30.3 and 28.13 $dS \cdot m^{-1}$, respectively. To clarify this phenomenon, it should be said that natural zeolite has a very open framework with a network of pores that offers a large surface area for trapping and exchanging valuable nutrients. Natural zeolites adsorb salinity ions, which enter cavities of the material and consequently, the salinity levels of the effluent are decreased Turan (2008).

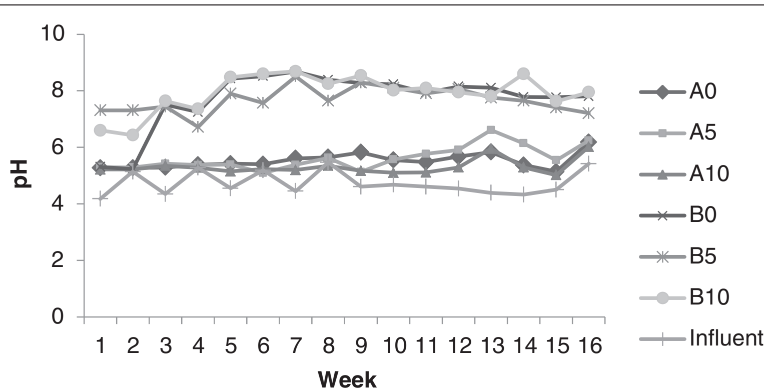

Figure 3 Changes in the pH values of the effluent during the study for all treatments.

Table 4 Mean concentration of heavy metal in the treatment effluents

Soil texture	Zeolite application (%)	Cd	Ni	Cr	Pb
		mg · L^{-1}			
Loamy sand	0	0.11a*	3.09a	0.82a	1.13a
Loamy sand	5	0.11ab	2.87b	0.81a	1.12ab
Loamy sand	10	0.10b	2.69c	0.64b	1.06b
Clay loam	0	0.03c	0.47d	0.06c	0.31d
Clay loam	5	0.03c	0.53d	0.03c	0.38c
Clay loam	10	0.03c	0.50d	0.03c	0.37c

*Values in any column followed by the same letter do not differ at the 0.05 significance level.

pH

Figure 3 demonstrates fluctuations in effluent pH values during the study for all treatments. The mean value of influent pH during the study period was equal to 4.73. The mean effluent pH values for loamy sand and clay loamy soil were 5.48 and 7.77, respectively. There was a significant difference between the mean effluent pH values of loamy sand and clay loamy soils. Soil pH affects all chemical, physical, and biological properties of the soil Brady and Weil (2008). The effect of soil pH on specific microorganisms, soil microbial biomass, microbial activity and, more recently, on microbial community structure have been already investigated Pietri and Brookes (2008). In previous studies, it was shown that clay loamy soil decreases the influent acidity and effectively increases the effluent pH. They also discovered that a significant effect ($p < 0.05$) on effluent pH values is measured based on the volume of applied zeolite. Along with zeolite application increase, the pH value of the effluent also increased. The mean of effluent pH values for 5% and 10% zeolite were equal to 6.49 and 6.75, respectively. Applying 10% zeolite resulted in the increase in the effluent pH values of loamy sand and clay loamy soil from 4.73 to 5.31 and 7.92, respectively. Zeolite has a high cation exchange capacity and is able to adsorb positive cations such as hydrogen and sodium. Therefore, with increasing zeolite content of the soil, the effluent pH increased as well. This finding is consistent with previous studies (Shanableh and Kharabsheh 1996; Mahabadi et al. 2007; Noori et al. 2007; Perez-Caballero et al. 2008; Ahmed et al. 2010).

Heavy metal reduction

The stabilization of Cd^{2+}, Ni^{2+}, Pb^{2+}, and Cr^{3+} in control and treatment lysimeters was measured. Table 4 shows the concentrations of Cd^{2+}, Ni^{2+}, Pb^{2+}, and Cr^{3+} in the effluents obtained from different treatments. As shown in this table, soil texture had a significant effect on the reduction of Cd^{2+}, Ni^{2+}, Pb^{2+}, and Cr^{3+} in the effluent. Furthermore, lower concentration of these heavy metals in the effluent obtained from clay loamy lysimeters was seen comparing loamy sand lysimeters. This result is likely due to the particle size, specific surface area and CEC of the soils. Clay loam has a smaller particle size and a higher specific surface area than loamy sand soil; and because of that, it was able to more effectively remove these elements from the influent than the loamy sand soil.

The lysimeter effluents' changes in Cd^{2+} concentration in all treatments is revealed in Figure 4. According to Table 4, soil texture had a significant effect on Cd^{2+} concentration. The mean percentages of Cd^{2+} reduction for clay loam and loamy sand soils were equal to 76.41% and 12.24%, respectively. Additionally, application of 5% and 10% zeolite had no significant effect on Cd^{2+} adsorption (Table 4). Three weeks after starting the experiment, results uncovered that the loamy sand soil lysimeters with 5% and 10% zeolite could adsorb 28.6% and 52.4% of Cd^{2+} from the influent, respectively. Our results also indicate that during the first weeks of the study, application of zeolite could decrease the leaching of Cd^{2+}. These results could be related to the low influent pH values, suggesting that pH value is an important factor which effects Cd^{2+} leachability Shanableh and Kharabsheh (1996).

Figure 5 shows Pb^{2+} concentration of the effluent in different treatments. Except the loamy sand lysimeter without zeolite application (A_0), the Pb^{2+} concentration

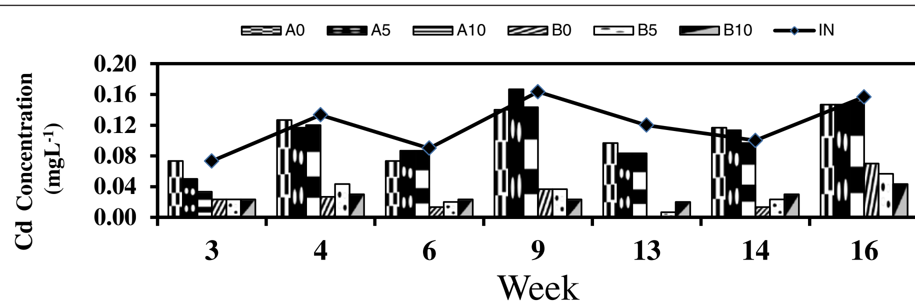

Figure 4 Effluent Cd^{2+} concentration for all treatments during the study period.

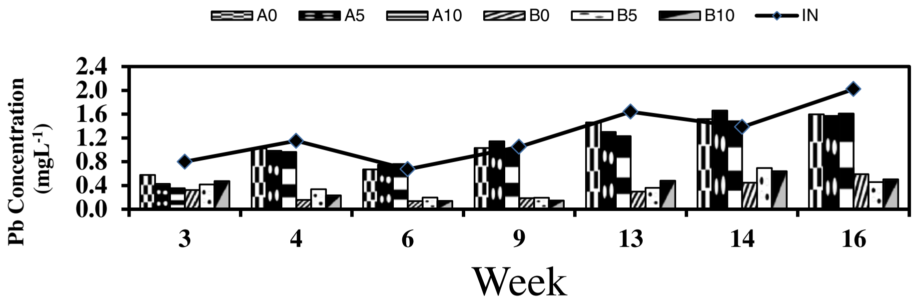

Figure 5 The Pb^{2+} concentration of the effluent from different treatments.

of effluent during the first 3 weeks in all treatments was similar. In all treatments except A_0 (30%), removed Pb^{2+} percentage from the influent was approximately 50%. While application of zeolite significantly (p < 0.05) increased the Pb^{2+} sorption in the loamy sand lysimeters, no significant difference was found (p < 0.05) between application of 5% and 10% zeolite in clay loamy soil in terms of Pb^{2+} concentrations in the effluent (Table 4). The mean percentages of Pb^{2+} removal identified for A_0, A_5, A_{10}, B_0, B_5, and B_{10} were 10.4%, 14.9%, 17.2%, 75%, 68%, and 69% respectively.

Application of zeolite had a significant effect (p < 0.05) on effluent Ni^{2+} and Cr^{3+} concentrations in loamy sand soil (Table 4). The results showed that application of 10% zeolite reasonably reduced Cr^{3+} and Ni^{2+} concentrations. The maximum concentrations of Ni^{2+} and Cr^{3+} in the effluent were observed in lysimeters without application of zeolite. The mean concentrations of Ni^{2+} in effluents obtained from lysimeters with 0%, 5%, and 10% zeolite were 1.78, 1.7, and 1.6 $mg \cdot L^{-1}$, respectively. The mean concentrations of Cr^{3+} in effluents obtained from lysimeters with 0%, 5%, and 10% zeolite were 0.437, 0.423, and 0.334 $mg \cdot L^{-1}$, respectively (data are not shown).

Leachate from an organic fertilizer factory was used as the influent that consisted of many different cations. Therefore, the results of this study were different from previous studies which used solutions with specific elements.

There are some experimental reports from the fact that increasing zeolite content results in lower Cd^{2+} and Pb^{2+} concentrations in the leaching solution Lin et al. (1998; Oste et al. 2002; Mahabadi et al. 2007); however, in this study, the application of zeolite only increased the adsorption during the first 3 weeks. This inconsistent result could be attributed to the chemical characteristics of organic fertilizer factory leachate that was used as the influent in this research. The pH value of the influent used in this study was very low compared to the previous studies Mahabadi et al. (2007). It has been confirmed that sorption is mainly dominated by ion exchange, as H^+ ions compete Pb^{2+} ions for ion exchange sites (Sheng et al. 2009; Wang et al. 2009; Yang et al. 2011). Thus, the higher the pH value (i.e., lower H^+ concentration), the higher the sorption of Pb^{2+}, Cr^{3+}, and Ni^{2+} on the surface of zeolite. Yang et al. (2011) demonstrated that the sorption of Pb^{2+} in low pH can be attributed to ion exchange between Pb^{2+} and H^+/Na^+ on the surface of NKF-6 zeolite. Nevertheless, the presence of other cations such as K^+ and Na^+ in the solution influences the sorption of heavy metals. The competitive cations hinder the exchange of heavy metals through zeolite, which is a well-known phenomenon in ion exchange systems Yang et al. (2011).

With the exception of the first three influent applications and in contrast with clay loamy soil treatments (B_0, B_5, and B_{10}), the loamy sand soil treatments could not adsorb Pb^{2+}. The CEC of the loamy sand soil and zeolite were saturated with cations and anions such as Na^+, Ca^{2+}, Cl^-, which existed in the influent upon first leachate applications. Exchangeable ions, such as Na^+, K^+, Ca^{2+}, and Mg^{2+} commonly occupy clinoptilolite Ackley and Yang (1991). These cations are exchangeable with certain cations in the solution, such as Pb^{2+}, Cd^{2+}, Zn^{2+}, and Mg^{2+} Erdem et al. (2004). Some investigators have used a natural zeolite additive to reduce Pb^{2+}, Cd^{2+}, and Ni^{2+} leaching from a soil contaminated with the mixtures of the three metals. The results from the repeated leaching column experiments confirmed the selectivity of the additive, which brought about a satisfactory leaching reduction of Cd^{2+} and Pb^{2+} (Ackley and Yang 1991; Shi et al. 2009; Zhang et al. 2010). Wang et al. (2009) exhibited that K^+,

Table 5 Bulk density at the beginning and at the end of the experimental period

		A0	A5	A10	B0	B5	B10
Bulk density ($g \cdot cm^3$)	Beginning	1.88a*	1.94a	1.91a	1.50a	1.60a	1.64a
	Ending	1.68b	1.55b	1.65b	1.25b	1.20b	1.10b

*Values in any column followed by the same letter do not differ at the 0.05 significance level.

Table 6 Saturated hydraulic conductivity (m/day) for all treatments before and after application of leachate

Zeolite application	Loamy sand			Clay loam		
	0	5	10	0	5	10
Before start of experiment	3.25a*	3.17 a	2.88 a	1.73a	1.58a	1.44a
End of the experiment	3.25a	3.17 a	2.88 a	0.36b	0.29b	0.14b

*Values in any column followed by the same letter do not differ at the 0.05 significance level.

Na^+, and Li^+ (as competitive ions) decreased the Pb^{2+} sorption at pH < 6. The influence of these cations on the sorption of heavy metals can also be attributed to the hydrated radius. K^+ is smaller than those of the other two cations and therefore, the effect of K^+ on reduction of Pb (II) adsorption is more obvious than those of Na^+ and Li^+. Li et al. (2009) investigated the effect of Li^+, Na^+, and K^+ on Cu sorption in GMZ bentonite, and similar results were found.

Bulk density

Table 5 shows the comparison between the bulk densities at the beginning and end of the experimental period. Because the soil texture of loamy sand was coarser than clay loam, the bulk density of loamy sand soil was higher than clay loamy soil. Adding zeolite to the soil caused an increase in the bulk density at the beginning of the experiment. Nonetheless, irrigation of the soil with the leachate of organic fertilizer factory significantly decreased the bulk density in all treatments ($p < 0.05$) at the end of the study period (Table 5). This result is consistent with previous studies (Chandrasekaran and Rajkannan 2003; Bhardwaj et al. 2007; Malla et al. 2007).

Saturated hydraulic conductivity (K_{sat})

The high K_{sat} in loamy sand soil was due to its coarser texture as compared to clay loamy soil (Table 6). Fine particles are a major cause of reduced soil K_{sat} in surface soils, particularly when irrigated with sodic waters with low electrolyte concentration Felhendler et al. (1974).

Along with increasing zeolite content in clay loamy soil treatments, K_{sat} decreased. Zeolite particle size distribution (0.4 to 2 mm) also affected K_{sat}. For loamy sand soils, application of zeolite effectively reduced soil hydraulic conductivity. Lin et al. (1998) also reported in their research that application of zeolite in sandy and loamy soils effectively reduced the average particle size and consequently lowered hydraulic conductivity.

However, it is inferred that the existence of a large amount of sodium in the influent solution causes enhancement of the sodium adsorption ratio (SAR) that consequently causes dispersion of the soil matrix. Clay dispersion in the clay loamy soil and high total suspended solids (TSS) are the major causes of hydraulic conductivity reduction. Previous studies have also mentioned a significant decrease in soil hydraulic conductivity after the application of effluent (Magesan et al. 1999; Tarchitzky et al. 1999; Halliwell et al. 2001; Levy et al. 2005; Francisca and Glatstein 2010).

Infiltration

Domestic and industrial wastewater does have usually high amount of sodium and this causes a reduction of water infiltration through the soil over the time. Reduced water infiltration inhibits soil profile's leaching and further concentration of sodium and other toxic ions Vogeler (2009).

As illustrated in Figure 6, infiltration decreased by adding zeolite to the soil. This is due to the tininess of the zeolite compared to the soil particles. These zeolite small particles can fill spaces of the soil particles and clog the pores of the soil. In loamy sand soil, no significant difference was revealed ($p < 0.05$) between amount of accumulated infiltration at the beginning and at the end of experimental period. Oppositely, in the clay loamy soil, soil infiltration significantly decreased along

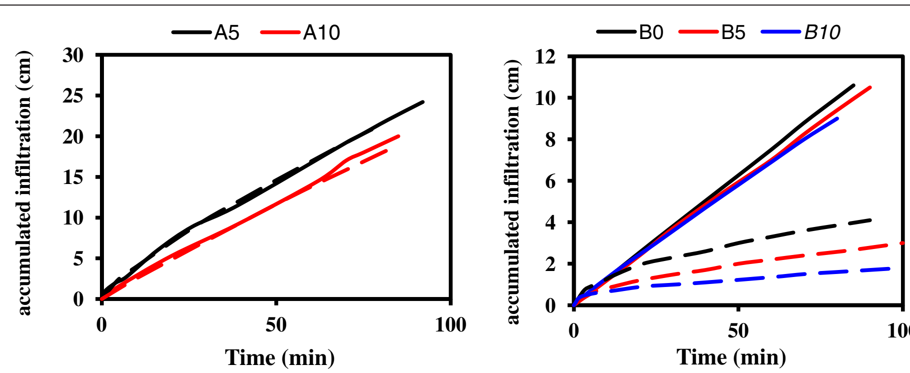

Figure 6 Accumulated infiltration at the beginning (Solid Line) and end (Dash Line) of experimental period.

with increasing zeolite content at the beginning and at the end of the experimental period (data are not shown). As illustrated in Figure 6, soils with 10% zeolite (A10 and B10) posses the least amount of infiltration and the lowest hydraulic conductivity.

Furthermore, high values of TSS and SAR of the leachate can reduce soil permeability. Lado et al. (2005) showed that using longer than 10 years of effluent for irrigation would cause abatement of infiltration. Deletic and Fletcher (2006) demonstrated that clogging of the soil due to the deposition of sediment may cause a decrease in infiltration. Some studies have reported long-term and constant use of water with a high adjusted SAR value, which would lead to a reduction of the soil infiltration and permeability (Wallach et al. 2005; Graber et al. 2006).

Conclusions

In sum, we attempted to investigate the effect of land treatment and zeolite on reduction of heavy metal concentrations in leachate. Most outstanding results of this research could be listed as below:

1. Land treatment plays a significant role in the elimination of heavy metals from leachate.
2. Soil texture has a fundamental role in the elimination process.
3. In loamy sand soil, different levels of zeolite had significant effects on the reduction of heavy metal concentrations in the effluent.
4. Irrigation of the soil with leachate reduced bulk density and infiltration and saturated hydraulic conductivity of the soil due to high SAR and TSS of the leachate. Last but not least, zeolite had a damaging effect on mentioned processes because of its role in the release of Na and its effect on physical properties of the soil.

Competing interests

The authors declare that they have no competing interest.

Authors' contributions

SMJM collected the experimental data. SHT, MH and PN carried out the supervision on the data analysis. SEH helped in laboratory analysis.

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